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FINAL REPORT

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27 JUNE 1965 THROUGH 31 JANUARY 1966

DESIGN, DEVELOPMENT AND TESTING DEW POINT HYGROMETERS FOR THE NASA/GEMINI PROGRAM

Submitted to

NASA Manned Spaceflight Center

in partial fulfillment of

Contract No. NAS 9-4793 (Article VII, B)

31 January 1966

PREPARED BY

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N66 28378

ABSTRACT

This document describes the design, development and testing of a Dew Point Hygrometer System developed by Cambridge Systems, Incorporated, Newton, Massachusetts for use in the NASA/Gemini Manned Spaceflight Program.

The system is a hand held instrument designed to measure and visually display the dew point, ambient, and surface temperatures inside a spacecraft.

The information in this document covers the background and requirements for development of the system, major milestones in the performance of the contract, description of the resultant configuration, highlights of the engineering development, summaries of qualification and acceptance testing results, and recommendations for additional engineering development of future systems.

Author

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SECTION 1

INTRODUCTION

1.1 Background

Cambridge Systems, Incorporated (CSI), Newton, Massachusetts has recently completed Contract NAS 9-4793 with the National Aeronautics and Space Administration's Manned Spaceflight Center in Houston, Texas. The contract called for CSI to design develop, fabricate, test, and deliver four miniature dew point hygrometer systems having the dual capability of measuring dew point temperatures and air or surface temperatures.

It was planned to employ the system as part of the spacecraft instrumentation in the extended orbital missions of the NASA Gemini Program.

In previous space flights only limited information had been obtained regarding environmental relative humidity or dew point temperature. This information is necessary to evaluate the performance of water removal systems and to permit the most desirable spacecraft environment to be maintained, in terms of both pilot comfort and equipment protection.

CSI had previously developed miniature dew point hygrometers under Air Force Contracts AF19(604)-8812, and AF19(628)-410, Army Contract DA36-039-AMC-03763(E) and NASA Contract NAS 9-2917. The latter effort produced a miniature hygrometer system designed to measure dew point temperatures in life supporting atmospheres as encountered in spacecraft.

The concepts and hardware developed under these contracts provided a reliable point of departure for development of the NASA/Gemini units, however, a considerable engineering effort was required to meet the stringent environmental criteria and size, weight and input power constraints associated with manned space flight.

1.2 Program Milestones

The major milestones in the performance of this contract were, of course, the hardware delivery dates, however, a number of other events are almost equally important. The significant hardware and reporting milestones are summarized in Table 1.

1.3 Nomenclature

Four complete systems were delivered under this contract, a prototype, a qualification test article, and two flight articles. The system configuration is shown in Figure 1. The nomenclature and model numbers assigned to the systems are identified below:

System Name: NASA/Gemini Dew Point Hygrometer System

Model Numbers: Sensor - CSI Model 137-S4-TH, NASA, Part No. EC32003
Control Unit - CSI Model 137-C5, NASA, Part No.EC32005.
Cable - NASA Part No. 32004.

Serial Numbers: 1 through 5*.

1.4 Scope and Organization of Report

This is the final report of Contract NAS9-4793. As such it documents and summarizes results of the entire contractual effort and provides conclusions and recommendations based on experience and results obtained during this program.

Although an effort has been made to facilitate interpretation of the information in this report without extensive cross referencing to other documents, no attempt has been made to reproduce the data from tests which have been reported elsewhere. Where results are considered important, they have been summarized in the narrative of this document.

The remainder of this report is organized as follows:

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* Serial No. 1 was the prototype, Serial No. 2 was the initial qualification test unit, however, it was destroyed during testing, and was replaced by Serial No. 3. Serial Nos. 4 and 5 were delivered as flight articles.

Section 2, Engineering, describes the requirements, results and highlights of the engineering development effort.

Section 3, Testing, summarizes the testing carried out on the completed systems and indicates the extent to which the performance and design goals were satisfied.

Section 4, Conclusions and Recommendations, provides CSI's conclusions concerning system design and makes recommendations for additional research and development in dew point hygrometry for application to spaceflight missions.

Section 5, References, lists the documentation and drawings developed under this program.

TABLE 1 PROGRAM MILESTONES

Milestone Event							1965	1966
	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
Performance Period [1]	21							31
Prototype System (S/N 1) Delivered [2]			25					
Qualification Testing (S/N 2,3,4) [3]				10		18		
Flight Systems (S/N 4,5,) Delivered [2]					23,28			
Qualification System (S/N 3) Delivered						19		
Acceptance Test Procedure			5					
Qualification Test Procedure			5					
Inspection Plan			5					
Failure Modes, Effects and Criticality Analysis			27					
Preservation, Packaging, Handling, Storage and Shipping Procedures				3				
Drawings (Initial Releases)			24,30			24		
(Final Sepias and Prints)							7	
Instruction Manuals						26		
Final Acceptance Test Report (S/N 1,4,5)							13	
Final Qualification Test Report (S/N 2,3,4) [2]								14
Monthly Progress Reports		27	27	27	29	29		
Final Report								14

1. Contract NAS 9-4793, dated 17 Jun 65, was received by CSI 21 Jun. 65. Performance period was extended to 31 Jan. 66 by Contract Mod. No. 3.

2. Each hygrometer system was shipped with Acceptance Test Data Sheets and the NASA-MSC System Historical Record.

3. Hygrometer system S/N 2, damaged beyond repair during qualification testing, was replaced by S/N 3. System S/N 4, a flight article was subjected to only a portion of the EMI Tests.

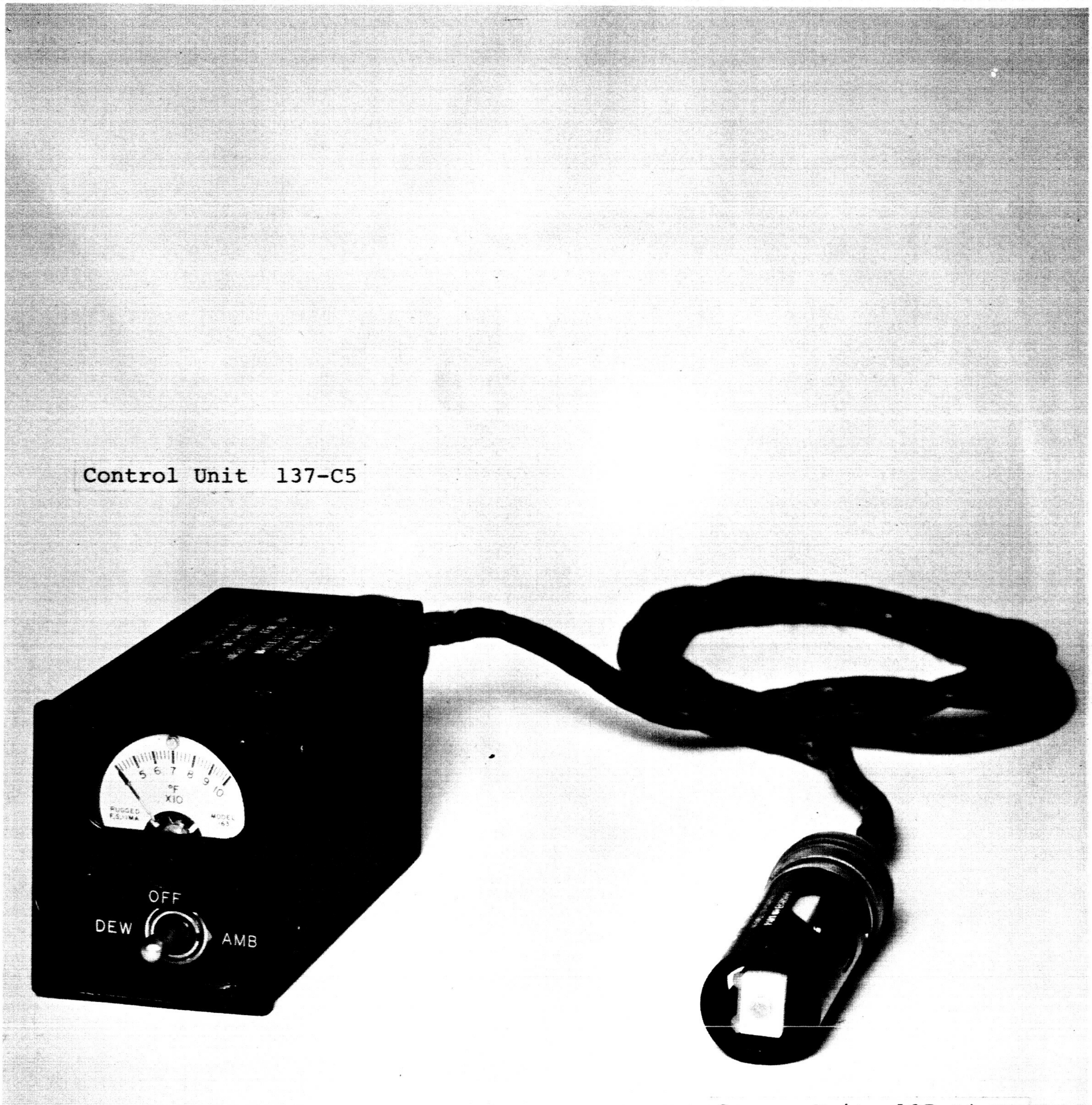


Figure 1. Dew Point Hygrometer System

SECTION 2

ENGINEERING

2.1 Objectives

The basic objective of this program was to design, fabricate, and qualify for manned space flight an accurate and reliable instrument for measuring dew point, air and surface temperatures in spacecraft systems. It was planned that the dew point hygrometer system would be utilized on the extended orbital flights of NASA's Gemini program.

2.2. Requirements

The following specifications were established to assure compatibility of the delivered systems with the rigorous requirements of the manned space flight environment:

The required system was to consist of a hand-held instrument designed to measure and visually display the dew point, ambient, and surface temperatures existing inside a spacecraft. The system was to be designed for minimum weight and size, for low power dissipation characteristics, and for long term reliability during flight. The major performance and operating specifications established for the system are summarized below:

2.2.1 Range

Capable of reading dew point, ambient, and surface temperatures between 40° F. and 100° F.

2.2.2 Response

The time for a 63% response to a 20° F. step change in either dew point or surface temperature was to be 10 seconds, or less.

2.2.3 Accuracy

Within $\pm$ 1° F. over the entire operating range.

2.2.4 Stability

Total Drift was not to exceed $\pm$ 1% of full scale over the entire operating range.

2.2.5 Output

Initially, both output meter for direct readout and voltage output for telemetry transmission were specified. The telemetry function was later eliminated.

2.2.6 Power Dissipation

For a nominal supply voltage of 28 VDC, steady state power consumption was to be 3 watts (or less) when measuring the dew point temperature at relative humities between 50% and 100%.

2.2.7 Weight and Size

The entire system including cable was to weigh less than 2 pounds 4 ounces, and was constrained to fit within the following dimensional envelope:

Sensor: A cylinder 1 inch in diameter and 3 inches long.

Control Unit: 6 inches long, 2 inches wide, 2.5 inches high.

In addition to these performance characteristics, the stringent operating environments and conditions of manned space flight imposed several additional constraints on system design (See Table 2). The most significant of these was the 100% oxygen atmosphere in the spacecraft. This precluded use of a motor driven aspirator and dictated design of an essentially no-flow (diffusion) sampling system.

The design effort required under this contract was directed toward achieving these specified performance levels and conditions within a framework of maximum reliability and measurement accuracy

In the paragraphs that follow, functional and circuit descriptions of the resultant system, and discussions of engineering highlights and problems encountered in the effort are provided.

2.3 Functional Description

The functional block diagram for the dew point hygrometer system is shown in Figure 2. The Sensor unit depicted in the diagram contains a mirror surface which is thermally bonded to a small thermo-electric cooling module. The module, when excited with direct current of proper polarity, causes heat to be pumped from the mirror and thus lowers the temperature of the mirror surface. As the mirror temperature reaches the dew point, the process of condensate formation on the mirror surface commences. The presence of the condensate on the mirror surface causes the visible light reflection characteristic of the mirror to change.

TABLE 2

ENVIRONMENTAL CRITERIA

ENVIRONMENT	NON OPERATING	OPERATING
TEMPERATURE	0 to 160°F	40 to 100°F
PRESSURE	23.5 to 1.0 x 10^{-12} psia	15.5 to 5.0 psia
RELATIVE HUMIDITY	15 to 100%	15% to 100%
OXYGEN ATMOSPHERE	100% O_2 at pressures between 5.0 and 15.5 psia	100% O_2 at pressures between 5.0 and 15.5 psia
ACCELERATION	0 to 7.5 g	0 g and 1.0 g
RANDOM VIBRATION		
20 to 400 cps	Linear Increase form 0.02 to 0.09 g^2/cps	Constant at 0.008 g^2/cps between 20 and 500 cps.
400 to 800 cps	constant at 0.09 g^2/cps	
800 to 1000 cps	linear decrease from 0.09 0.01 g^2/cps	
1000 to 2000 cps	Constant at 0.01 g^2/cps	
SALT SPRAY	5% salt solution	Not applicable

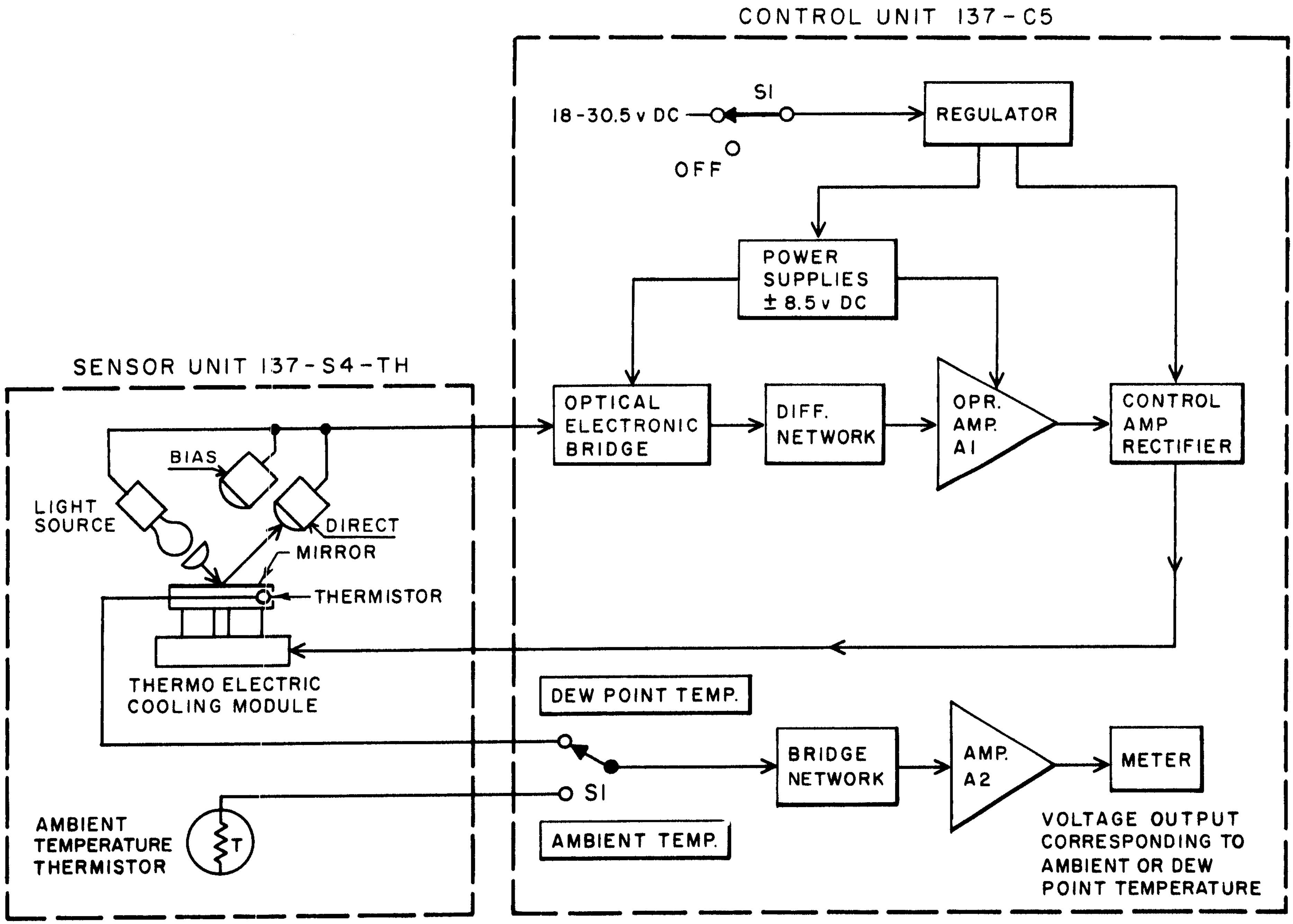


Figure 2 Dew Point Hygrometer System, Function Block Diagram

CAMBRIDGE SYSTEMS, INC

The mirror surface is illuminated by an incandescent source in such a fashion that the change in reflectivity is detected by the DIRECT and BIAS photocells which develop a difference voltage that unbalances the photoelectric bridge. The output of the sensing bridge is applied to the input of the operational amplifier, which in turn controls the direct current supplied to the thermoelectric cooling module in direct proportion to the input signal. Using this proportional direct current to excite the cooler in a negative sense, i.e., causing the mirror to become cooler when a decrease in condensate occurs, the system will stabilize on and control about a particular dew layer thickness. A measurement of the mirror temperature under stabilized conditions is a measurement of dew point. This is accomplished by a thermistor which senses temperature as a resistance change. The thermistor is electrically connected in a Wheatstone bridge circuit the output of which is amplified to deflect the needle of the meter. Measurement of air or surface temperature is accomplished by an identical thermistor located at the end of the sensor unit.

2.4 Circuit description

The schematic diagram for the Dew Point Hygrometer System is shown in Figure 3. The circuit is designed to operate as follows:

The formation of condensate on the mirror surface causes a reduction in the amount of light received at the photocell labeled DIRECT and a consequent change in the device resistance. This photocell and a second photocell labeled BIAS, comprise the optical portion of the bridge circuit. Resistors R39 through R42 and potentiometer R45 (labeled BALANCE) complete the conventional bridge. The bridge output signal is taken from the arm of R45 and from the common point of the photocells. The signal from the common point on the photocell is fed into the input of the operational amplifier. Stable operation is insured by use of over 60 db of negative feedback. The output of the operational amplifier is then fed to Q9 which serves as a driver stage for the control amplifiers Q7 and Q8. An unbalanced condition in the photocell bridge causes Q7 or Q8 (whichever is biased on) to become more conductive and permits current to flow through the thermoelectric cooler TE-1, causing its surface to become cool.

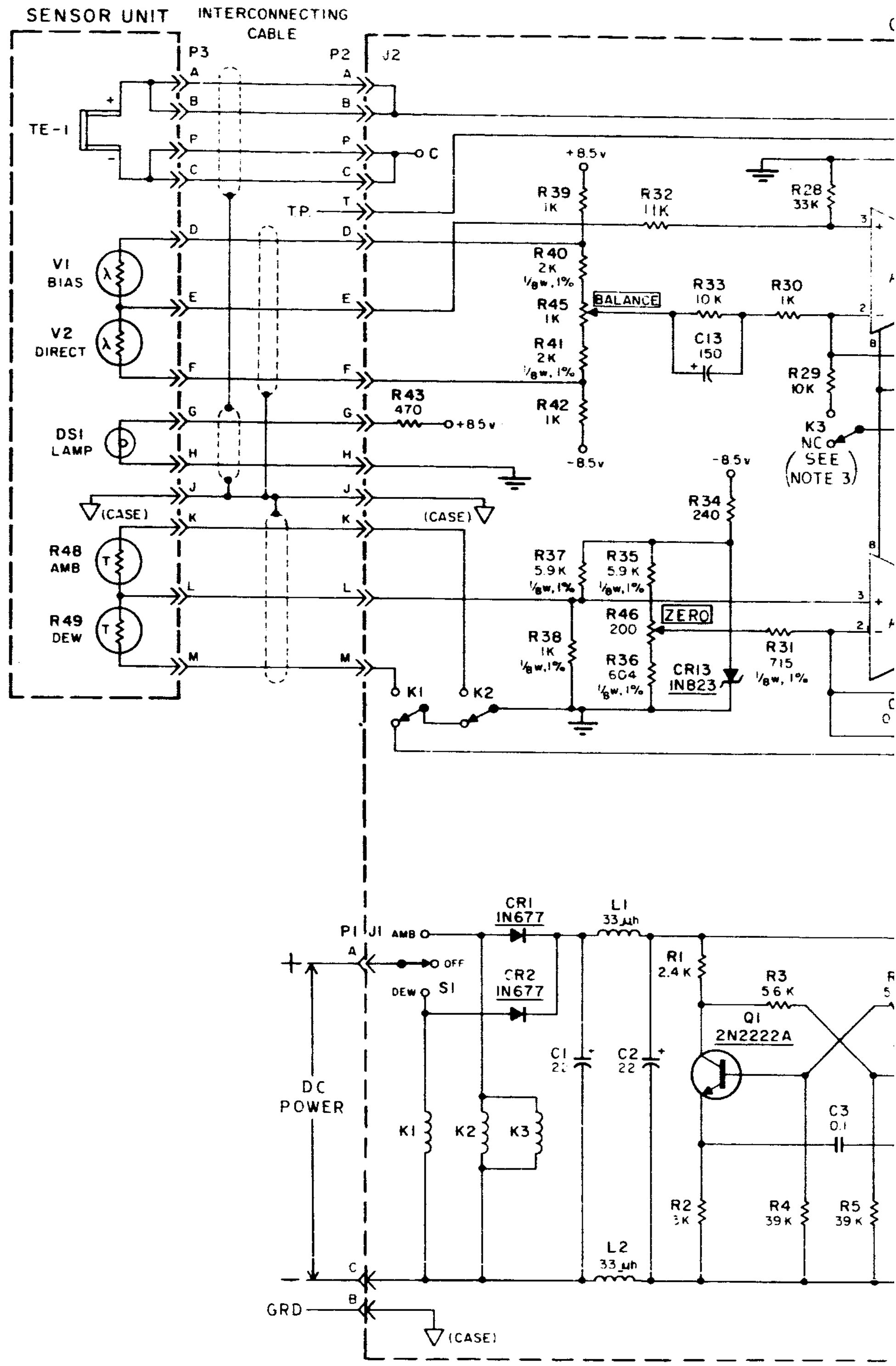
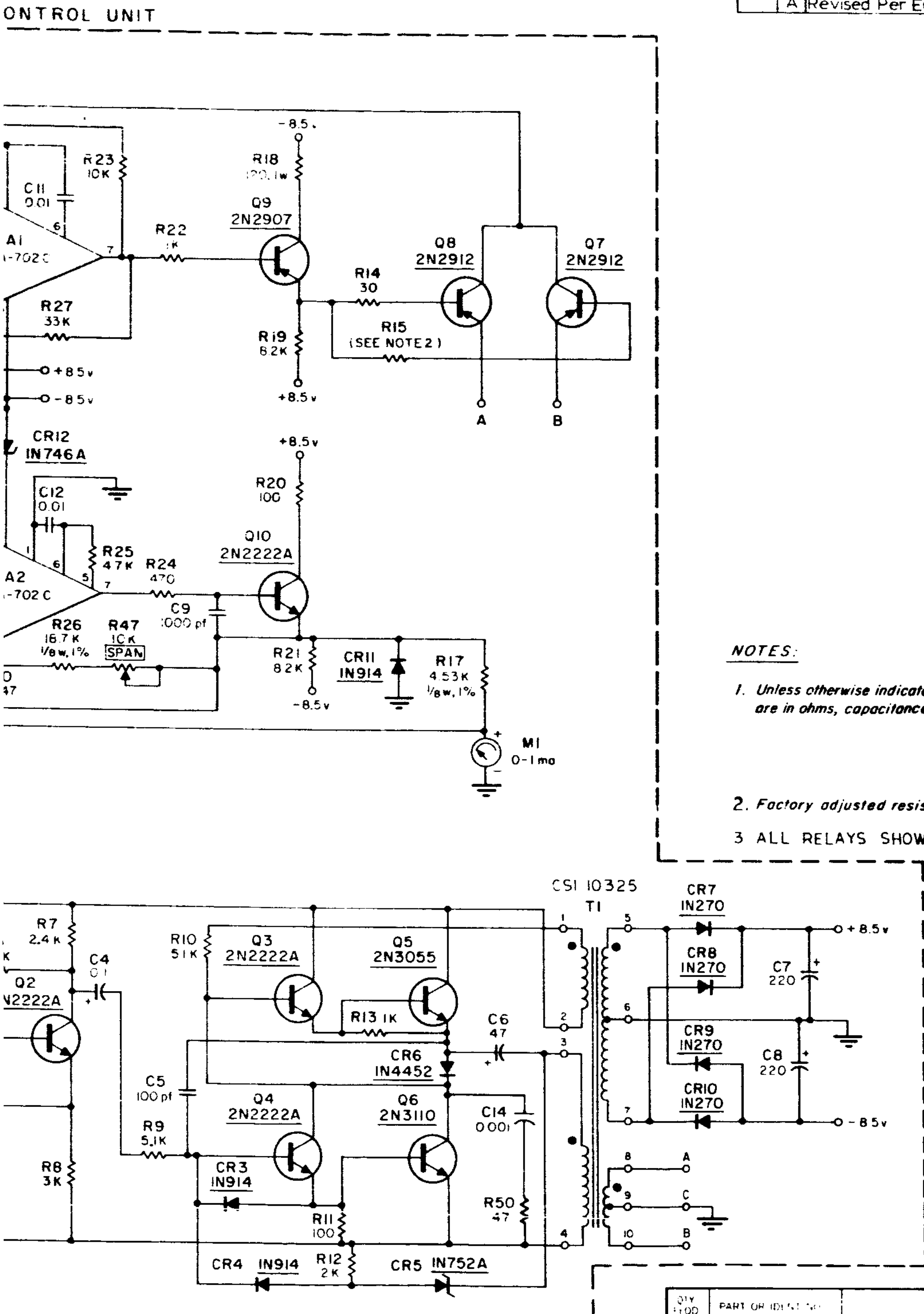


Figure 3 Dew Point Hygrometer System,

11-①

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	Revised Per ECO No 1005 R50, C14	10/21/65	



NOTES:

1. *Unless otherwise indicated resistances are in ohms, capacitances are in μf*
2. *Factory adjusted resistance*
3. ALL RELAYS SHOWN IN DE-ENERGIZED POSITION

QTY REQD	PART OR IDENT NO	DESCRIPTION	ITEM NO

LIST OF MATERIALS

chematic Diagram

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCE ON
DECIMALS .XX .XXX
FRACTIONS
ANGLES
SURFACE ROUGHNESS
MATERIAL
FINISH OR TREATMENT

DR 17 OCT 65
CHK
APPD
APPD

cambridge systems, inc.
NEWTON MASSACHUSETTS

Dew Point Hygrometer System
Schematic Diagram -Sensor 137-S4-TH -Control Unit 137-C5

SIZE	CODE IDENT NO		REV
D		10254-Z	A
SCALE		SHEET 1 OF 1	

When the surface has cooled to the dew point, condensate forms on the mirror surface and tends to force the photocell bridge toward the balance point. This reduces the amount of cooling proportionately until an equilibrium situation is established, whereby a film of condensate is maintained on the mirror surface. The BALANCE potentiometer thus determines the dew layer film thickness at equilbrium.

Satisfactory operation of the hygrometer can be deduced from the behavior of the mirror surface temperature as indicated by the meter. As soon as the switch is placed in the dew position the mirror surface temperature is at the temperature of the metal parts in the sensor, typically the ambient storage temperature. The cooling begins immediately and proceeds to reduce the mirror temperature to a point slightly below the dew point temperature. During this time a thin film of dew is forming on the mirror surface. When sufficient dew has formed, the temperature will rise to the true dew point temperature maintaining a dew film of constant reflectivity and essentially constant thickness. The time required for the dew build up will vary, being less for high relative humidity and high aspiration rates.

The readout circuitry operates independently of the control circuitry. The thermistors, one (R49) embedded in the mirrored surface and the other (R48) located at the tip of the sensor unit, utilize a conventional bridge arrangement to obtain a voltage corresponding to the temperature sensed. The bridge output is fed into an operational amplifier A2 which ultimately drives the meter by means of Q10.

The input power supply for the Dew point Hygrometer System may range from 18.0 VDC to 30.5 VDC (28 VDC nominal). This power is fed into a transistorized inverter-regulator operating at approximately 3KC. The inverter supplies power for a positive 8.5 volt supply, a negative 8.5 volt supply and a low voltage 2 ampere supply to operate the thermoelectric cooler. The two 8.5 volt supplies are used to power the operational amplifiers and the optical and temperature measuring bridges.

2.5 Sensor Development

The primary goals for designing the sensor shown in Figure 4 were

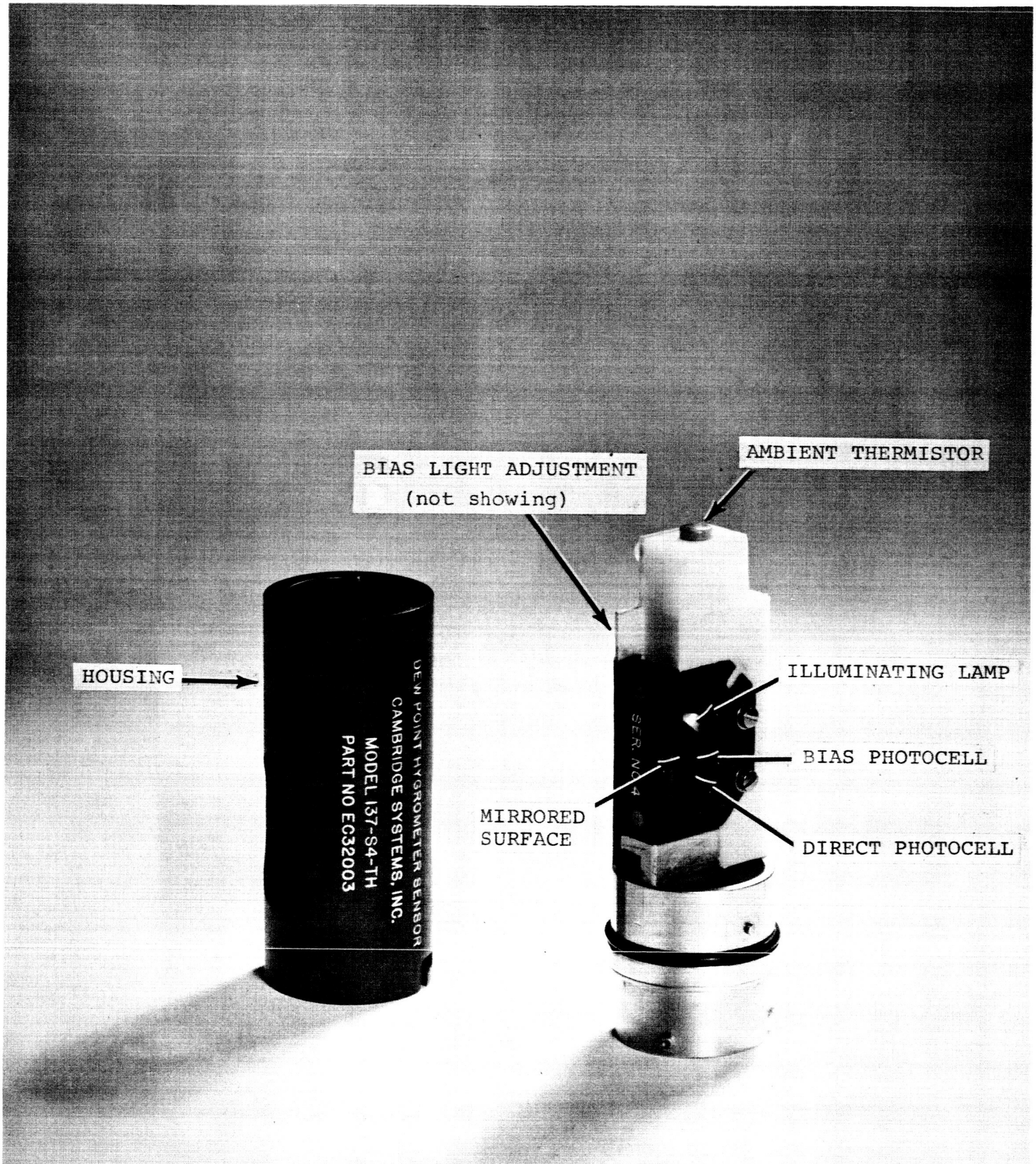


Figure 4. Sensor Unit

small size, high accuracy, and fast measurement response. The configurations developed under previous contracts provided a point of departure, but considerable modification was necessary to meet the requirements of this program. For example, the earlier models, designed to operate over a much wider range of temperatures, employed a platinum thermometer as the basic sensing element. The reduced span of temperatures required for the Gemini hygrometers made thermistors practicable for use.

2.5.1 Temperature Sensors

Thermistors were particularly attractive due to their relatively large change in resistance for a given change in temperature (as compared to platinum thermometers) thus requiring less signal amplification. In addition, thermistors are considerably less expensive and smaller than platinum thermometers. The output of a thermistor is not as linear as that of a platinum thermometer, but over the 60° F. range of interest for this program the units selected vary less than $\pm 0.5^{\circ}$ F.

2.5.2 Light Source

Another improvement achieved in the Gemini units was the incorporation of a lens between the light source (a 0.02 candle power lamp) and the mirror surface. In the lamps available for this application, the location of filaments varies to such an extent that their center of illumination is difficult to control within the necessary tolerances. The addition of a lens between the lamp and the mirror reduces the effect of this variation and also improves collimation of the beam of light impinging on the mirror.

2.5.3 No-Flow Measurement

One of the most difficult aspects of sensor design grew out of the stipulation that the measurements were to be obtained under no-flow conditions, i.e., no aspiration system was to be employed.

Three basic problems had to be overcome: first, the lack of an air flow through the sensing chamber would make it difficult to continuously reject heat from the hot side of the thermoelectric cooler (used to bring the mirror surface down to the dew point temperature). Second, fairly large openings in the housing would be necessary to permit diffusion to the sensing chamber. This would have to be accomplished without compromising the structural rigidity of the sensor or admitting extraneous light sources. Finally, without an air flow the response of the instrument would not be as fast as with an aspirated system.

The heat rejection problem was overcome by selecting sensor components and encapsulating material with high thermal conductivity, thereby providing an effective heat sink. The high thermal mass of the connector assembly effectively serves as a heat sink for transient operation (i.e., single dew point measurements).

The exclusion of direct light was achieved by designing a suitable housing port arrangement and blocking the remaining light paths with specially designed light shields and molded sections of isofoam or potting compound.

The approach toward achieving the desired response characteristics in the air/surface temperature measurement was focused primarily on the thermistor mount itself. A configuration incorporating the smallest thermal mass consistent with the structural and functional requirements of the system was selected. The front portion of the mount was molded from an aluminum fill compound (Emerson Cumings 51AF). The material is strong and has high thermal conductivity, thus providing good temperature response for the surface temperature measurement.

2.5.4 Bonding Technology

Another improvement designed into this system was in the method of bonding the mirror to the thermoelectric cooler. Previous models of miniature hygrometers had employed an epoxy bond between mirror and cooler. After long usage thermal cycling tends to break down the bond and the mirrors separate from the coolers. Consequently, the system is no longer capable of accurately measuring dew point temperatures significantly below the ambient temperature (depression becomes poor). For this program, a new method was developed whereby a low temperature solder (melting temperature approximately 170° F) was used for the bond. This approach not only improved the structural characteristics of the bond, but also provided better thermal conductivity for the purpose of heat transfer between mirror and cooler.

The technology involved in the soldering approach is extremely difficult at this time due to the characteristic sensitivity of thermoelectric coolers to concentrated heat (the solder used in coolers melts at 230° F also limiting the applications of these coolers).

2.6 Control Unit Development

Design of the electronics package (control unit 137-C5) for this system was primarily influenced by the size/weight constraints, input power limitation, and high reliability requirements.

Highlights of the resultant design and certain problem areas are discussed below.

2.6.1 Integrated Circuits

Integrated components were used wherever possible for their small size, high reliability, and extremely low power dissipation characteristics. The integrated circuits selected for amplifiers A-1 and A-2 were especially attractive due to their relatively long history of high performance and good reliability.

2.6.2 Cooler Control Circuit

A unique cooler control circuit was designed for this project. The thermoelectric cooler being a high current - low voltage (low internal resistance) device makes the design of a high-efficiency rectifier system quite difficult. A good silicon rectifier can have as much as 1 volt drop at 2 amps, thereby limiting its efficiency to a maximum of 30%. The design developed for this system eliminates the rectifiers and therefore its high dissipation. The cooler is driven by two small transistors that perform the double function of rectifier and regulator. This scheme has improved system efficiency to 80%.

A switching type regulator was initially considered to conserve input power, but due to the increased circuit complexity and difficult filtering requirements, it was abandoned in favor of the series type regulator/inverter.

2.6.3 Meter Damping

Relays K1 and K2 are connected in such a way that when system power is off, they short the meter out, thus damping meter movement due to vibration, shock, etc. This feature serves to protect the meter, when the power is off such as during the ascent phase of flight.

2.6.4 Temperature Compensated Voltage Reference

To achieve stable temperature output readings over the entire operating range of the instrument, a temperature compensated voltage reference source has been incorporated.

SECTION 3

TESTING

In addition to numerous component level and subassembly checks performed during system fabrication and assembly, two major testing activities were accomplished on the completed units. The most extensive of these was a qualification test program conducted primarily to demonstrate that design environmental objectives had been achieved. System performance was determined by means of formal acceptance tests witnessed by the Boston Defense Contracts Administration Services Representative (DCASR).

Comprehensive reports have been issued covering both of these activities, consequently the data will not be reiterated here. The most significant results are summarized, however, to show that the system as designed did attain the required performance levels and that environmental criteria had been satisfied.

3.1 Qualification Testing

Qualification testing was conducted in accordance with the CSI test procedure outlined in reference 5.1.3. The test article was first inspected and checked in accordance with the acceptance test procedure then subjected to the required environmental test, and finally inspected and acceptance tested to determine if any physical, functional, or performance degradation had occurred. The sequence and results of the qualification testing are summarized in Table 3. The only discrepancies noted were:

1. A photocell failure during the decompression test. This failure was not repeatable in subsequent testing and is attributed to a faulty photocell.
2. A severe voltage transient and high current loading during testing which resulted in damage to four control unit components (they could not be replaced due to the potting configuration), and
3. An out-of-specification EMI source which necessitated minor system modification.

TABLE 3

QUALIFICATION TEST HISTORY

TEST	DATE	REMARKS
Initial Acceptance	10 Sept. 65	Start of Qual. Testing; Serial No. 2
Low Temperature	10 Sept.	
Decompression	11-13 Sept.	Failed; faulty photocell
Decompression	15-17 Sept.	
Humidity	17-27 Sept.	
Vibration	28 Sept.	
Thermal Vacuum	30 Sept.-1 Oct.	
EMI Susceptibility	8 Oct.	Failed; system subjected to a voltage transient and excessive current loading; burned out four components. Repair not possible due to potting configuration.
EMI Susceptibility	18 Oct.	Serial No. 3 replaced No. 2 as the qual. test unit; test results satisfactory.
EMI Radiation	18 Oct.	Failed; Exceeded limits for interference at 22 and 44 MHz. Modification of control unit converter circuit required to eliminate source of radiation. Mod. not possible on Serial No. 3 due to potting configuration. Test rescheduled after mod. of Serial No.'s 4 and 5. Remainder of qual. program continued later with Serial No. 3.
Initial Acceptance	20 Oct.	Serial No. 4
EMI Radiation	20 Oct.	Performance satisfactory; radiation problem eliminated.
Final Acceptance	22 Oct.	Shipped 23 Oct.
High Temperature	8 Nov.	Serial No. 3
Temperature-Altitude	8 Nov.	Serial No. 3
Final Acceptance	18 Nov.	Serial No. 3 qualified except for portions of EMI radiation test. Units 4 and 5 modified to eliminate radiation source.

3.2 Acceptance Testing

Acceptance tests were performed on all deliverable items to demonstrate that system performance was within specified limits and that the equipment was free from material, construction, workmanship, and functional deficiencies. The performance standards and criteria of primary interest are summarized below.

3.2.1 Power Consumption

Measured for input voltages between 18 and 30.5 VDC. Input power was not to exceed 3 watts when the system was measuring dew point temperatures corresponding to a relative humidity of 50% or greater at the nominal supply voltage of 28 VDC.

Results

System power dissipation increases with decreasing dew point temperatures, primarily due to the greater amount of current drawn by the thermoelectric cooler to achieve greater depression (difference between ambient and dew point temperature). Consequently, a system which dissipates 3 watts at ambient/dew point temperatures corresponding to 50% relative humidity is satisfactory.

All systems delivered under this contract were within this tolerance. Only one was considered marginal. System No. 5 required 3.08 watts when measuring dew point temperature at 50.6% relative humidity. Extrapolation of typical power dissipation versus relative humidity curves shows that the system would require 3.1 watts at 50% relative humidity. A deviation of this order is negligible when test equipment tolerances are considered.

3.2.2 Calibration

Each instrument was to be calibrated for dew point and ambient temperatures between 40° and 100° F. A single calibration curve was to be used for both. System output was to be within 1.2° F of this curve.

Results

No discrepancies or anomalies were experienced in the calibration of these systems. Maximum deviation from linearity was less than 1.2° F.

3.2.3 Accuracy

Total system error when measuring either a dew point temperature or ambient temperature was not to exceed $\pm 1^{o}$ F.

Results

System error did not exceed $\pm 1^{o}$ F in any of the delivered items. System No. 5 was rejected when it exhibited a 1.5^{o} F error during acceptance testing. After the system was reworked and adjusted, however, it was again subjected to the entire acceptance test procedure, this time with satisfactory results.

3.2.4 Dimensions

Each unit was measured to verify that it was within the following dimensional envelope.

Sensor - 3 inches long, 1 inch in diameter.

Control Unit- 6 inches long, 2 inches wide, 2½ inches high.

Results

The height and width of the control unit exceeded the specified dimensions by 1/16 inch. This deviation resulted from the addition of a band 1/32 inch thick by 3/16 inch wide which was brazed to the outside surface of the units' forward ends to provide greater structural rigidity. Measurement of the units exclusive of this band showed them to be within the specified envelope.

3.2.8 Weight

Total system weight was not to exceed 2 pounds, 4 ounces.

Results

All systems weighed less than 2 pounds, 4 ounces.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

The final configuation and performance of the 137-S4-TH Sensor and 137-C5 Control Unit are considered by CSI to represent a significant improvement over other miniature dew point hygrometer temperature measuring instruments developed to date. This should not be construed as an indication that this system is the ultimate instrument for such applications. It is in fact, only a single step in a continuing research and development effort.

This section of the report summarizes conclusions drawn concerning the achievement of design goals and provides recommendations for additional engineering development.

4.1 Conclusions

4.1.1 Performance Criteria

Analyses of the data obtained during development, qualification, and acceptance testing show that the systems delivered under this contract achieved the required levels of performance in terms of accuracy, power dissipation, linearity, stability, and dynamic range. Response time data verify the achievement of design goals in the dew point and surface temperature modes of operation.

4.1.2 Environmental Criteria

Achievement of the environmental design goals is evidenced in data from the qualification tests (see reference 5.1.3). No noticeable degradation of performance was noted when the system was subjected to either the operating or non-operating environmental conditions specified in the statement of work. The only area in which the data do not conclusively verify system performance are those associated with the response time of the air temperature measurement in the simulated no-flow condition of the spacecraft. This is primarily due to the fact that the test facilities required to provide more meaningful data could not be obtained in the time available for program completion. Consequently the degree to which the design goals had been achieved cannot be stated in quantitative terms.

4.2 Recommendations

As the result of experience gained during the performance of this contract, several areas have been identified where significant improvements may be realized. Consideration of the following is recommended for further development effort.

4.2.1 Thermoelectric Coolers

Although the small size and high capacity of these components make a miniature hygrometer system feasible in the first place, large performance variations presently require careful matching and adjustment of sensors and control units. The major problem results from variations as great as 40% in the optimum current of the coolers. Consequently, the degree to which sensors and control units may be interchanged is quite limited. Furthermore, the present system design does not permit the cooler current control to be adjusted to the point where maximum operating efficiency is achieved. It is anticipated that input power reductions on the order of 10% could be realized by incorporating such adjustment devices.

4.2.2 Light Source

The filament-type lamps presently employed as light sources in the dew point sensors are the most vulnerable components in the system. The present contractual requirement specifying potting of all electrical connections effectively precludes replacement of the bulb during space flight. Three alternative means of eliminating this weakness are recommended:

1. Use a filament lamp with lower voltage and higher current resulting in a more rugged lamp. Present lamp (5 volts at 15 ma) was chosen for low power consumption. A lamp using 3 volts and 60 ma has considerably greater reliability but more than twice the power consumption. This approach is inexpensive and has high certainty of improvement.
2. Use a neon glow lamp. These lamps have no filament which would be subject to vibrational failure and are also known to have exceptionally long life. Two difficulties associated with this approach are the high voltage required (about 70V) and the fact that at present no information is available on a neon lamp of a small enough size.

3. Use a solid state light source. Advances in the field of semiconductor diode light emitters has advanced to the point where such a device would be feasible. Here the main problems are high price, higher power than a filament lamp and the fact that a special unit would have to be designed and built for this application. This approach is expensive and has low certainty of success, but the potential improvement is great.

4.2.3 Aspiration

As noted in the section on Engineering Development, the lack of aspiration and the no-flow sampling presented problems in heat rejection from the thermoelectric cooler. The resultant design is satisfactory for applications involving short duty cycles and long rest intervals, making use of the thermal mass of the sensor as a heat sink. As the measurement cycle is increased, however, the heat dissipated by the cooler begins to degrade its cooling capability and reduces the accuracy of the air temperature measurement. Further, the large orifices necessitated by diffusion sampling do not lend themselves to the overall concept of instrument rigidity or exclusion of light, and therefore increase the complexity of the instrument.

Finally, the technique of diffusion sampling is not compatible with the requirement of rapid air temperature measurement response. The response of the temperature sensor is excellent for surface temperature measurements but poor for free air measurements. The requirements for a rugged reliable surface sensor and those for a fast response air sensor to be used without aspiration are mutually exclusive. It is recommended that considerable improvement could be obtained by retaining the surface temperature element in a form similar to the present unit but in addition to utilize a third temperature sensor of low thermal mass for the sole purpose of a fast response air temperature measurement. This would require four switch positions - off, dew point, surface, air. In addition to the use of this air sensor, it would be desirable to use some form of forced aspiration. A squeeze bulb or bellows would probably be the most effective approach.

4.2.4 Thermistor Mounting

One apparent mechanical weakness in the system was experienced in the prototype unit (Serial No. 1). The leads from the air/surface temperature thermistor broke, apparently due to prolonged use of the instrument to measure surface temperatures. In its present configuration the arrangement is prone to lead breakage because of the incompatibility of rigid potting material at one end of the leads, and repeated flexing of the leads against the potting. Additional engineering development is recommended to eliminate this weakness. The two approaches currently envisioned are to utilize leads designed for greater flexibility, and to decrease the overall mass of the sensor.

4.2.5 System Power

If power dissipation is a major constraint in development of future systems, rechargeable nickel-cadmium batteries could be employed as the power source. They could be trickle charged at about 0.1 to 0.2 watt and used at a duty cycle of about 10:1, i.e., a 3-minute measurement every 30 minutes.

The thermoelectric coolers used in these systems typically operate more effectively from batteries due to their low voltage, high current characteristics.

4.2.6 Readout Accuracy and Resolution

Improvement of both readout accuracy and resolution can be achieved in future systems. The accuracy of the readout is currently limited by a linearity requirement specified primarily to accommodate the telemetry system. When the telemetry output was deleted, the linearity requirement was not, resulting in an unnecessary readout error in certain areas of the scale. The scale itself is linear, however, thermistor output is typically an S-curve. An improvement in overall accuracy could be achieved by distorting the scale to correspond directly to the thermistor output characteristics.

Resolution of the measurement can also be improved. Presently, the readability is to the nearest $\frac{1}{2}^{\circ}$ F, resulting from the small space allowed. Better readability can be obtained in this space if two meter scales are provided with a switch, 40° to 70° F, and 70° to 100° F.

4.2.7 Package Improvement

Additional refinements in the electronics packaging could be achieved by designing the control unit to incorporate separate, replaceable modules for the power supply and control/readout sections. These would be mounted on printed circuit boards. Another factor worth considering is the fact that replacement of only half of the unit would be necessary in the event of malfunction; currently, component malfunction requires scrapping of the entire unit.

SECTION 5

REFERENCES

5.1 Documents

5.1.1 Inspection Plan for NASA/Gemini Dew Point Hygrometer
(Control Unit 137-C5)
(Sensor Unit 137-S4-TH) dated, 5 August 1965

5.1.2 Acceptance Test Procedure for NASA/Gemini Dew Point Hygrometer
dated, 5 August 1965

5.1.3 Qualification Test Procedure for NASA/Gemini Dew Point Hygrometer
dated, 5 August 1965

5.1.4 Equipment Manual for NASA/Gemini Dew Point Hygrometer
dated, 5 August 1965

5.1.5 Acceptance Reports for NASA/Gemini Dew Point Hygrometer
Serial Nos. 1, 4, and 5 dated, 5 August 1965

5.1.6 Qualification Test Report for NASA/Gemini Dew Point Hygrometer
dated, January 1966

5.1.7 Monthly Progress Reports (1 through 5) dated 27 July, 27 August, 27 September, 29 October, and 29 November 1965.

5.2 Drawings

The drawings released under this contract are listed in Table 4.

TABLE 4

LIST OF DRAWINGS

Drawing No.	Description
C-10142A	Housing, Optical Component
C-10143C	Housing Mount Assy
B-10144B	Guide, Block, Thermistor
B-10145A	Block, Thermistor
B-10146	Shield, Light
B-10154	Retainer, Spring
B-10155A	Spring Compression
D-10156B	Sensor Assy
C-10212B	Chassis
C-10215B	Front Panel
C-10216A	Marking Drawing-Control Unit
C-10243	Marking Drawing-Sensor Unit
C-10244A	Sensor Circuit Board
D-10254ZA	Schematic Diagram, Dew Point Hygrometer System
C-10255A	Wiring Diagram, Control Unit
C-10256	Cable, Power/Telemetry
C-10257A	Cable, Sensor
B-10276	Spring, Bulb
C-10289	Potting Mold, Left Side
C-10291	Potting Mold, Right Side
B-10293	Tube, Potting Mold
A-10320	Encapsulating Mold
A-10322	Plug, Potting Mold
C-10325	Transformer, Inverter
B-10331	Block Assy, Air Thermistor
C-10334	Potting Mold Assy
B-10343	Clip, Light (Modified)
C-10469	Optical Component Assy
A-10472	Sensor Assy Instructions
C-11053	Optical Component Mount Support, Mach. Assy
C-11054A	Support, Optical Housing
C-11055B	Optical Component Mount
C-11056A	Lamp Holder
B-11057	Spacer, Sensor Assy
B-11058	Washer, Sensor Assy
B-11059A	Spring Holder, Sensor Assy
B-11122	Mirror

(30 Nov. 65)